odsil, H.C. and E.C. Greenhood
1951

U.E. Brock
R.E. Brock

STATE OF CALIFORNIA
DEPARTMENT OF FISH AND GAME
BUREAU OF MARINE FISHERIES

FISH BULLETIN NO. 82

A Comparison of the Populations of Yellowfin Tuna, *Neothunnus macropterus*, From the Eastern and Central Pacific

By
H. C. GODSIL
and
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ACKNOWLEDGMENTS

The present study, like most conducted at this laboratory, is essentially a cooperative work. The entire staff has helped at one time or another with some phase of the work, and this assistance is gratefully acknowledged. Especial thanks are extended to Mrs. C. J. Laing, Mrs. M. MacIntire and Mr. E. K. Holmberg, who did much of the detailed computations.

H. C. Godsil
E. C. Greenhood
September, 1951

A COMPARISON OF THE POPULATIONS OF YELLOWFIN TUNA, *NEOTHUNNUS MACROPTERUS*, FROM THE EASTERN AND CENTRAL PACIFIC

By
H. C. Godsil and E. C. Greenhood
Bureau of Marine Fisheries

INTRODUCTION

The present study is a continuation of the work published in 1948 by the senior author. At that time the attempt was made to determine whether or not the yellowfin tuna from Japan and from the Hawaiian Islands comprised populations distinct from and nonintermingling with that of the eastern Pacific region exploited by the California fleet. Using body measurements, empirical regression lines for those characters investigated were established for the eastern Pacific population, based upon 13 separate samples comprising a total of approximately 1,900 fish. It was found that, although these samples differed significally in a statistical sense from one another when tested by methods of analysis of variance, nevertheless all sample regression lines from these grounds conformed to the empirical population regression lines within narrow limits. When the data from the Japanese and Hawaiian samples were compared with the local population regression lines, it was found that in some characters these samples diverged from the local stock by amounts many times greater than the most divergent local sample. (Local, as used herein, refers to the eastern Pacific population.) The Japanese fish diverged more than the Hawaiian, but in all cases the direction of divergence was the same, suggesting a closer relationship between the Japanese and Hawaiian populations than existed between either of these with the local stock. The tentative conclusion was therefore drawn that the local, or eastern Pacific, stock of yellowfin tuna was separate and distinct from that of the central and western Pacific.

While this conclusion represented the most probable hypothesis upon which to formulate a management program, it was nevertheless based upon a single small sample from each of the two distant regions. Every effort was therefore made to obtain additional and larger samples in order to check this important conclusion.

In the summer of 1948 we succeeded in getting a sample of 58 yellowfin tuna caught in the vicinity of the Hawaiian Islands during the course of a cruise of the State's research vessel N. B. Scofield. This sample was derived in part from Johnston Island (16° 31′ N., 169° 25′ W.) and in part from those banks and islands situated between French Frigate Shoals and the island of Kauai. It is therefore a composite sample from the region rather than from any one specific area. The fish in this sample were relatively small and the range in body length extended from 224 to 851 millimeters. Three of the smallest fish were eliminated from the final sample because lack of small calipers prevented us from

making comparable measurements. The residual range in body length was from 514 to 851 millimeters. Because of this restricted size range, we attempted to supplement the sample by obtaining measurements from larger yellowfin delivered to the Honolulu markets at the time we were in port. Here we added 24 measurements to each series, made upon large, locally caught yellowfin, and thus extended the range to 1,638 millimeters.

A few months later we were fortunate in obtaining comparable measurements upon 94 fish in a load of yellowfin tuna caught in the central Pacific in February, 1949, by the vessel CALISTAR. Again, this is a composite sample as the fish in the load were caught in part at Palmyra Island (5° 52′ N., 162° 02′ W.) and in part at Fanning Island (3° 50′ N., 159° 20′ W.).

In April, 1950, before this analysis was completed, a small shipment of yellowfin tuna from the Fiji Islands was received by a local canner. Of this shipment we obtained measurements upon 13 yellowfin, all caught in the vicinity of Suva. These three additional samples afforded the desired opportunity to check the tentative conclusions drawn from the analysis of the original samples; and in addition, the four available samples from the central Pacific furnished material for a preliminary test of the homogeneity of the stock within that region.

METHODS

In the present study the methods used are identical with those discussed and explained in the earlier publication (Godsil, 1948). First, standard methods of analysis of variance were applied to the data. The results thus obtained yielded, in the aggregate, a statistical probability overwhelmingly supporting the original tentative conclusion that the central Pacific stock differed from that of the eastern Pacific. However, significant statistical differences of a smaller magnitude were found, in the earlier study, to exist between the several samples from the eastern Pacific. For this reason a distinction was made between biological and statistical significance. To evaluate the former, a method was evolved, used and described in the earlier study, by which the average squared distance separating a sample line from a second or empirical line could be calculated. Differences between sample and empirical lines were then evaluated in the light of sampling experience rather than in statistical probabilities. Briefly, if the sum of squared deviations of the sample is first calculated about the sample regression line (the line of best fit) and then calculated from any empirical population regression line, one obtains two values,

a. The variance of the sample about the sample line; and

b. The variance of the same sample about the population line. Inasmuch as the variates are the same, the difference between these two variances is proportional to the average squared distance separating the sample and population regression lines. Where these two lines are identical, the difference in the variances is obviously zero, and the difference in variances increases as the two lines become progressively more divergent, either in slope or intercept, or both. Thus the method enables one to arrive at a numerical difference between any two lines.

From the earlier work the magnitude of such differences was determined for successive samples of tuna from the eastern Pacific, compared

with an empirical eastern Pacific population line. The limit of such differences was then used to evaluate the corresponding differences found to exist between the empirical eastern Pacific line and samples derived from the central Pacific. We thus obtained a numerical measure of such differences to compare with the maximum difference actually observed in samples derived from the assumedly homogeneous eastern Pacific stock. In the present study this approximate biological evaluation is in complete accord with the results of the conventional statistical tests.

Throughout this work the function used to express the regression is

$$Y = a + bX + c\frac{1}{X}$$

where X in each case is the body length, and Y the second measurement entering into the respective regression.

For the line of best fit

$$\Sigma(Y_o - Y_c)^2 = \Sigma Y^2 - a\Sigma Y - b\Sigma XY - c\Sigma\frac{1}{X}Y$$

and the corresponding sum of squared deviations of a sample of variates measured from the empirical population line is given by the expansion of

$$\Sigma(Y_o - Y_c)^2 = \Sigma\left[Y_o - (a + bX + c\frac{1}{X})\right]^2$$

which is

$$= \Sigma Y^2 - 2a\Sigma Y - 2b\Sigma XY - 2c\Sigma\frac{1}{X}Y + Na^2 + 2ab\Sigma X + 2ac\Sigma\frac{1}{X} + b^2\Sigma X^2 + 2Nbc + c^2\Sigma\left[\frac{1}{X}\right]^2$$

in which the constant and regression coefficients are those of the empirical line, and the sums and products of variates are those of the actual sample under comparison. For a more complete discussion of the method the reader is referred to Godsil (1948, pages 9 and 10).

EFFECTS OF FREEZING

Unfortunately, the four samples from the central Pacific were not in comparable physical condition. The original Hawaiian sample consisted of 12 fish in excellent condition. They had been individually wrapped and frozen shortly after capture and were in perfect physical condition when thawed and measured after some months of storage.

The second Hawaiian sample, that of 1948, was taken by the crew of the N. B. Scofield. Each fish was measured fresh. Apart from any effects of freezing, storage and thawing the two Hawaiian samples were essentially comparable in physical condition.

The Palmyra sample, however, was caught commercially and stored for a period of five to six weeks in the hold of a tuna boat. Although storage conditions and temperatures on such a boat are quite satisfactory for the preservation of a food resource, the volume handled and stored results in a certain amount of distortion and minor physical damage to individual specimens. For purposes of the present study measurements from such fish are not entirely satisfactory. The characteristic regression line remains basically the same, but the scatter of individual measurements about this line is excessive, resulting in a mean square deviation that is higher than that obtained from fresh or carefully

TABLE 1

The Summation of All Comparable Measurements in Millimeters Made Upon the Fresh and the Frozen Fish of the 1948 Hawaiian Sample, With the Actual and Percentage Loss Caused by Freezing and Cold Storage

Sample N=54	Body length		Head length		First dorsal insert		2d dorsal insert		Anal insertion		Ventral insertion	
	Total	Average	Total	Average	Total	Average	Total	Average	Total	Average	Total	Average
Fresh	33,186	614.56	9,355	173.24	10,229	189.43	17,971	332.80	19,788	366.44	10,623	196.72
Frozen	32,739	606.28	9,339	172.94	10,200	188.89	17,862	330.78	19,606	363.07	10,499	194.43
Loss	447	8.28	16	0.30	29	0.54	109	2.02	182	3.37	124	2.29
Percent loss		1.35		0.17		0.29		0.61		0.92		1.16

preserved fish. As this has been repeatedly observed in numerous commercial samples, allowance must be made for it in interpreting the results. The Fijian sample was comparable with the Palmyra sample, but was, if anything, in poorer condition.

Apart from this consideration there is undoubtedly a degree of shrinkage in cold-stored fish. In a preliminary measure of this it appeared that the change in measurements caused by prolonged cold storage was not sufficient to change appreciably the resulting regression lines, although there was a slight upward displacement of "frozen" measurements in the case of second dorsal and anal insertion plotted against body length (Godsil, 1948, page 21). This preliminary test indicated that the regression lines of head length, first dorsal and ventral insertion, upon body length, were not appreciably affected.

The present material offered an opportunity to investigate further the effects of freezing upon proportional measurements. Fifty-five individuals of the tuna included in the 1948 Hawaiian sample were measured fresh upon capture. They were then promptly frozen and carefully stored at low temperatures. The fish were not individually marked. Four to five weeks later the fish were again measured. For the 54 fish on which duplicate measurements were made Table 1 shows separately for the fresh and frozen fish the summation of all comparable measurements, and the aggregate and the percentage loss for each.

In general the actual shrinkage is small and, with one exception, is proportional to the magnitude of the initial dimension. Thus, the length of the head is the least measurement and shows the least change. The body length is the greatest and shows the greatest change. The measurement of the ventral insertion, although roughly comparable with the measurement of the first dorsal insertion, shows a shrinkage far in excess of the latter. The reason is not apparent.

The effect of shrinkage upon the regression lines is shown in Figure 1. Here the individual regression lines for both the fresh and the frozen samples are shown superimposed. In four of these regressions, namely, head length, first dorsal insertion, second dorsal insertion and anal insertion, all on body length, the line for the frozen sample is displaced slightly above that of the fresh sample. In the case of the ventral insertion the two lines are practically coincident.

It is apparent that in the four specified regressions freezing and cold storage cause a slight upward displacement of the resulting regression lines. Figure 1 suggests that this effect is greatest in the case of head length and second dorsal insertion, less in the case of first dorsal and anal insertion and negligible in the case of ventral insertion. In general, the comparable lines are in all cases approximately parallel.

The magnitude of this displacement can be measured in several ways. One of the simplest is to compute, over the same range of body length, the sum of the calculated ordinates of both the fresh and the frozen regression line, thus:

$$\Sigma Y_z = Na_z + b_z\Sigma X + c_z\Sigma\frac{1}{X}$$

where subscript z designates the respective quantity pertaining to the frozen regression line, and:

$$\Sigma Y_f = Na_f + b_f\Sigma X + c_f\Sigma\frac{1}{X}$$

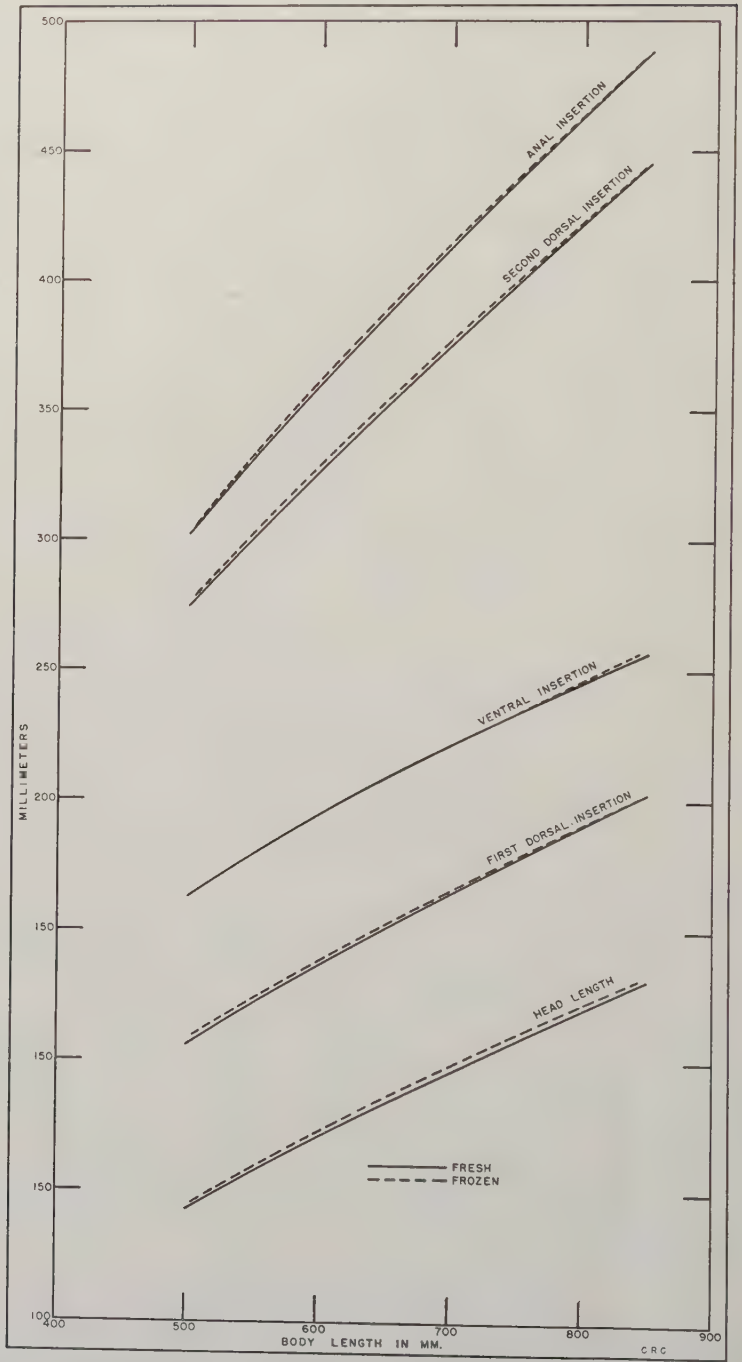

FIGURE 1. A comparison of the regression lines derived from measurements made upon the 1948 Hawaiian sample before and after freezing and cold storage

where subscript f designates the respective quantity pertaining to the fresh regression line. As ΣY is required only over the range of the frozen sample, N, ΣX and $\Sigma\frac{1}{X}$ would theoretically be the same in both lines and actually equal, respectively, to the total number of ordinates and the sum of all the X's and $\frac{1}{X}$'s within this range. As these values are not available, and in the case of the $\frac{1}{X}$'s, not readily obtainable, it will suffice for the present purpose to use the values of N, ΣX and $\Sigma\frac{1}{X}$ derived from the frozen sample, which will yield a close approximation to the required values. Combining the two equations will then give the total difference in the sum of the ordinates of the two curves, thus:

$$\Sigma Y_z - \Sigma Y_f = N(a_z - a_f) + \Sigma X(b_z - b_f) + \Sigma\frac{1}{X}(c_z - c_f).$$

If this difference is divided by N, the quotient tells the actual average linear distance separating the two regression lines, and the sign of the difference confirms the direction of displacement of the frozen variates.

The magnitudes of the present average differences, thus determined, are as follows:

Head length	1st dorsal	2d dorsal	Anal	Ventral
+ 1.839 mm.	+ 1.772 mm.	+ 2.166 mm.	+ 1.149 mm.	+ 0.085 mm.

Therefore for the five characters discussed the effects of freezing and cold storage are such as to raise the frozen regression line, without appreciable change in slope, above the fresh line by linear distances corresponding approximately with those tabulated above. Hence in evaluating differences observed between frozen samples and fresh material a preliminary approximate correction of this magnitude will probably enhance the validity of such comparisons.

The mechanics of applying the correction are simple. As the slope of the respective fresh and frozen line of a sample is to all intents the same, the correction may be applied directly to "a," which determines the relative height of the line. The correction may either be added to the "a" of the comparative fresh line, or subtracted from the "a" of the frozen sample line. If, for example, the appropriate correction of 1.839 mm. in the case of head length is subtracted from the value of "a" derived from the frozen line of the Hawaiian sample, the two regression lines, i.e., the fresh and the frozen line, should then be the same. That this is so is shown by Table 2 in which the figures shown are, for each

TABLE 2

The Average Squared Distance in Millimeters Between the "Fresh" and the Adjusted "Frozen" Line of the Hawaiian Sample. The Magnitude of "the Difference Between Lines" Reflects the Accuracy of the Applied Correction

	Head length	First dorsal	Second dorsal	Anal	Ventral
Variance from fresh line	7.2780	10.9585	14.2923	12.2166	10.2763
Variance from corrected frozen line	7.2761	10.9575	14.2921	12.2169	10.2763
Difference between lines	.0019	.0010	.0002	—.0003	.0000

regression, the difference in variance of the frozen variates deviated, first from the fresh regression line, and secondly from the frozen line to which the correction factor has been applied.

While the directional effect of freezing upon the resulting variates is consistent throughout, the magnitude of this displacement should be further investigated. Until better factors are available, the present approximations will be used in this discussion.

COMPARISON OF CENTRAL PACIFIC STOCK WITH THAT OF THE EASTERN PACIFIC

For the five characters discussed, the population regressions for the local or eastern Pacific stock of yellowfin tuna are given by the function

$$Y = a + bX + c\frac{1}{X}$$

in which the constant and coefficients have the values (ascertained in the earlier study) tabulated below.

Regression (on body length)	*a*	*b*	*c*	*Mean square*
Head length	83.27424	.212240	—20,467.8084	9.6352
First dorsal	95.19221	.226156	—23,086.8236	15.9386
Second dorsal	111.91554	.441629	—27,416.5652	20.5399
Anal	88.79915	.515977	—18,202.4687	25.2867
Ventral	58.22874	.257736	— 9,616.8242	19.3271

If these lines are used empirically to define the eastern Pacific stock, the individual central Pacific samples may then be compared directly with them, using the standard method of analysis of variance. The results summarized in Table 3 are derived uniformly from the analysis illustrated below, using the raw data without adjustment for the effects of freezing. The F values for the Palmyra and Fijian samples are much larger when this correction is applied.

1948 Hawaiian Sample

HEAD LENGTH ON BODY LENGTH

Source of variation	*Sum of squares*	*D. F.*	*Mean square*
Deviations from empirical eastern Pacific line	8,431.9038	79	
Deviations from Hawaiian sample line	1,149.0067	76	15.1185
Difference between lines	7,282.8971	3	2,427.6324

$$F = \frac{2,427.6324}{15.1185} = 160.5736 : P = \text{less than } .001$$

From such an analysis one must conclude that the central Pacific stock of yellowfin tuna is distinct from, and in all probability nonintermingling with, that of the eastern Pacific.

While the probabilities thus derived are convincingly high, it must be recalled that in the earlier study similar methods showed that the several samples derived from the eastern Pacific differed significantly in a statistical sense, although the actual differences between the respective lines was small. On page 8 of the earlier study this problem is discussed, and the concept of biological homogeneity is contrasted with that of statistical homogeneity. This led to the use of the average squared distance separating lines as a criterion for evaluating results.

TABLE 3

Summary Comparison, by Means of Analysis of Variance, of Individual Central Pacific Samples With Empirical Eastern Pacific Population Regression Lines No Correction Has Been Applied for the Effects of Freezing

Regression	1948 Hawaiian			Palmyra			Fijian		
	D. F.	F Value	Probability	D. F.	F Value	Probability	D. F.	F Value	Probability
Head length	3/76	160.57	Less than .001	3/91	76.49	Less than .001	3/10	24.00	Less than .001
First dorsal	3/76	40.69	Less than .001	3/91	22.14	Less than .001	3/10	8.98	Between .01 and .001
Second dorsal	3/76	23.97	Less than .001	3/90	49.81	Less than .001	3/10	6.25	About .01
Anal insertion	3/76	100.77	Less than .001	3/91	144.72	Less than .001	3/10	14.18	Less than .001
Ventral insertion	3/76	127.85	Less than .001	3/91	121.65	Less than .001	3/ 9	27.71	Less than .001

Table 4 is a reproduction of Tables 4 and 5 of Fish Bulletin No. 70. Samples 1 to 13 are derived from the eastern Pacific, and all "differences" discussed are measured from the corresponding empirical eastern Pacific population line. The Japanese, Hawaiian and Peruvian samples are the original ones discussed in the earlier study shown here for comparison with present results. The tabulated values of this table give an estimate of the extent of divergence that can be anticipated from any sample derived from the eastern Pacific population of yellowfin tuna. Also, they afford, with the empirical regression line, a means of deciding the identity or distinctness of populations elsewhere in the Pacific. Accordingly, in the following discussion the sample regression lines for the three recent samples from the central Pacific are compared, graphically and numerically, with the corresponding regression line characterizing the local population.

TABLE 4

The Difference Between the Individual Sample Regression Lines and the Eastern Pacific Population Regression Line, Expressed in Terms of the Difference in Mean Squares. This Table Is a Reproduction of Tables 4 and 5 of Fish Bulletin No. 70

Sample	Head length	First dorsal	Second dorsal	Anal	Ventral
No. 1	0.853	0.349	2.318	10.755	5.027
No. 2	0.411	0.938	6.943	4.428	1.081
No. 3	0.351	1.773	1.267	14.946	0.702
No. 4	1.761	0.979	0.797	1.964	0.700
No. 5	0.754	0.292	0.334	0.190	0.541
No. 6	0.124	0.853	1.373	1.388	2.513
No. 7	1.427	3.471	2.067	3.784	6.079
No. 8	1.754	2.876	2.353	4.798	1.272
No. 9	0.673	0.809	0.876	3.367	0.336
No. 10	0.287	0.077	0.024	2.166	0.958
No. 11	0.881	1.283	2.814	10.864	0.166
No. 12	2.333	1.778	2.793	7.795	1.204
No. 13	1.568	0.616	0.237	3.115	0.841
Japan	284.809	92.283	21.588	17.381	214.860
Hawaii	20.255	1.330	0.249	27.638	37.622
Peru	6.143	22.652	38.333	160.112	5.026

In the case of the Hawaiian sample two separate comparisons with the local population were made. One was based upon the sample obtained by the N. B. Scofield, and the other upon this sample plus the market measurements. The results of the two comparisons were in essential agreement. However, differences were in some cases accentuated in the analysis based upon the combined sample because in these proportions the slope of the lines characterizing the local and Hawaiian populations differed, and the divergence between the lines increased with increase in size of fish. Because the extended regression lines based upon the greater size range give a better picture of differences and similarities, the present comparison of the Hawaiian with the local population is based upon the total Hawaiian sample, including the market fish.

In Figures 2 to 6 the regression line characterizing the local population is represented by the long-dashed line. The short-dashed line is that of the Hawaiian sample: the solid line is the comparable regression line of the Palmyra sample, while the dash-dot line is that of the Fijian sample. In the computations an adjustment has been made for the effects of freezing.

HEAD LENGTH ON BODY LENGTH

Figure 2 shows that in the regression of head length upon body length the four lines differ appreciably. Selecting the local population line as a base for comparison, the regression lines of the Hawaiian and Fijian samples are in parts roughly parallel to this but removed from it a minimum distance of six to nine millimeters which is considerably in excess of anticipated variation for the samples from the eastern Pacific. Moreover, both these lines diverge progressively with increasing size of fish, indicating a slightly lesser slope. The regression line of the Palmyra sample has a decidedly different slope. Starting higher than the local line the Palmyra sample line intersects the local line at approximately 700 mm. body length, and from this point diverges increasingly at higher values. In the upper range the three central Pacific samples are in general similar. All possess a lesser slope and all fall, predominantly, appreciably below the eastern Pacific population line. The corresponding numerical values of this divergence are shown in Table 5. The differences

TABLE 5

Difference in Mean Squares Calculated From Sample and Eastern Pacific Population Regression Lines. Palmyra and Fijian Sample Regressions Have Been Adjusted for the Effects of Freezing

Sample	Head length	First Dorsal	Second Dorsal	Anal	Ventral
Hawaiian	92.1886	39.4118	28.4660	115.9449	109.5313
Palmyra	64.2164	36.8743	95.3632	260.4178	83.1996
Fiji	127.5253	67.5339	57.5855	184.1002	77.1631
Maximum local difference	2.333	3.471	6.943	14.980	6.079

in mean squares are excessively higher than in any sample obtained from the local population. In this character, therefore, the data indicate that the central Pacific stock differs from that of the eastern Pacific.

FIRST DORSAL INSERTION ON BODY LENGTH

In this regression (Figure 3) the Hawaiian and Fijian sample lines are again similar. Both are approximately parallel to the eastern Pacific line but lie at a distance of five to eight millimeters below it. Again the Palmyra line has a different slope. It intercepts the local line at about 740 mm. body length, and its divergence increases from this point on. The graph, in conjunction with the numerical values in Table 5, suggests that in this character also the central Pacific stock differs from that of the eastern Pacific, although the differences are not as pronounced as in the head length.

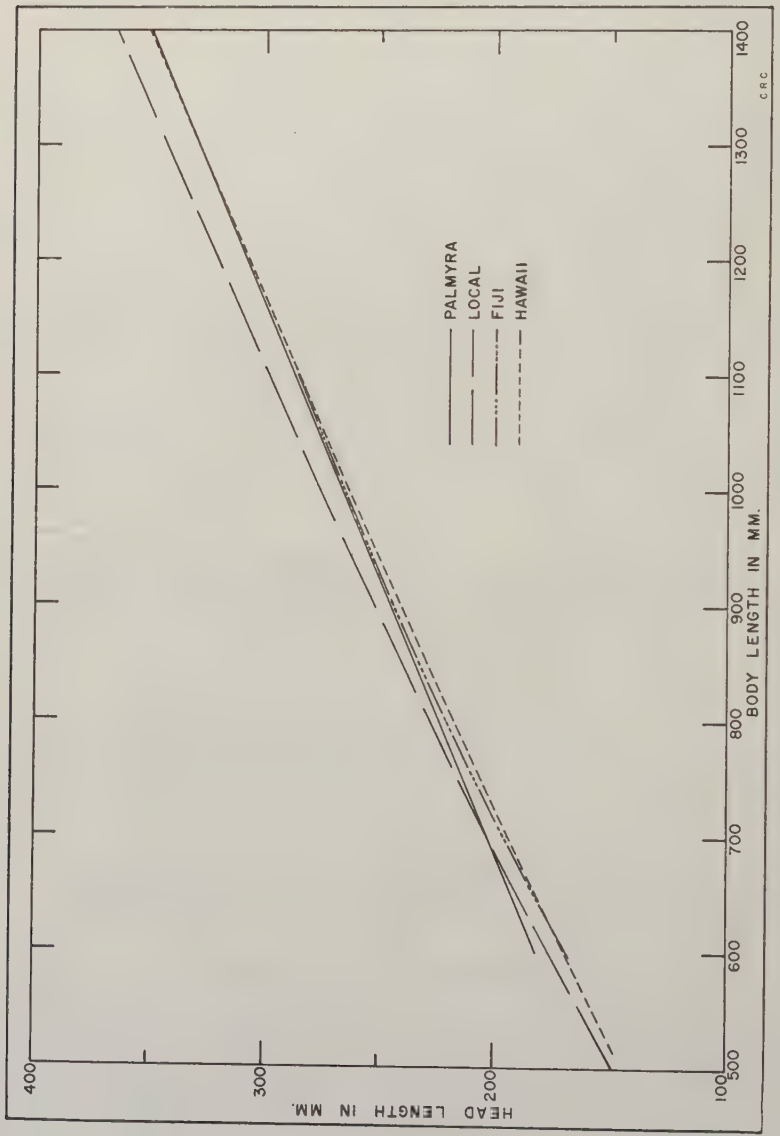

FIGURE 2. Comparison of the regression of head length on body length in the three central Pacific samples with the eastern Pacific population line

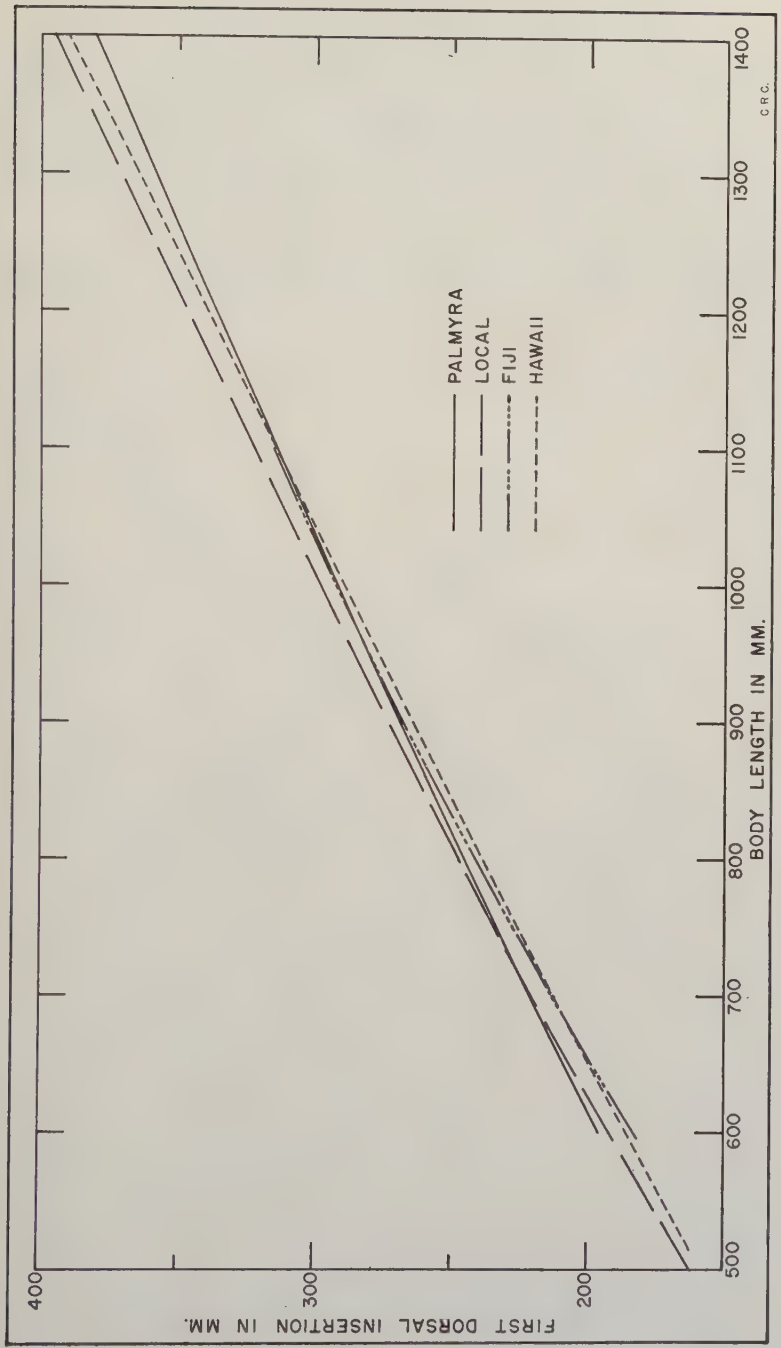

FIGURE 3. Comparison of the regression of first dorsal insertion on body length in the three central Pacific samples with the eastern Pacific population line

SECOND DORSAL INSERTION ON BODY LENGTH

In this character (Figure 4) the differences between the various samples are less than in any other. The Hawaiian and Palmyra samples are similar. Both have a slightly lesser slope, that of Palmyra being the least, and both lie slightly below the eastern Pacific line. In terms of mean square difference this divergence is many times greater than would be anticipated in samples from the local population. The two samples can therefore be considered different from the eastern Pacific stock.

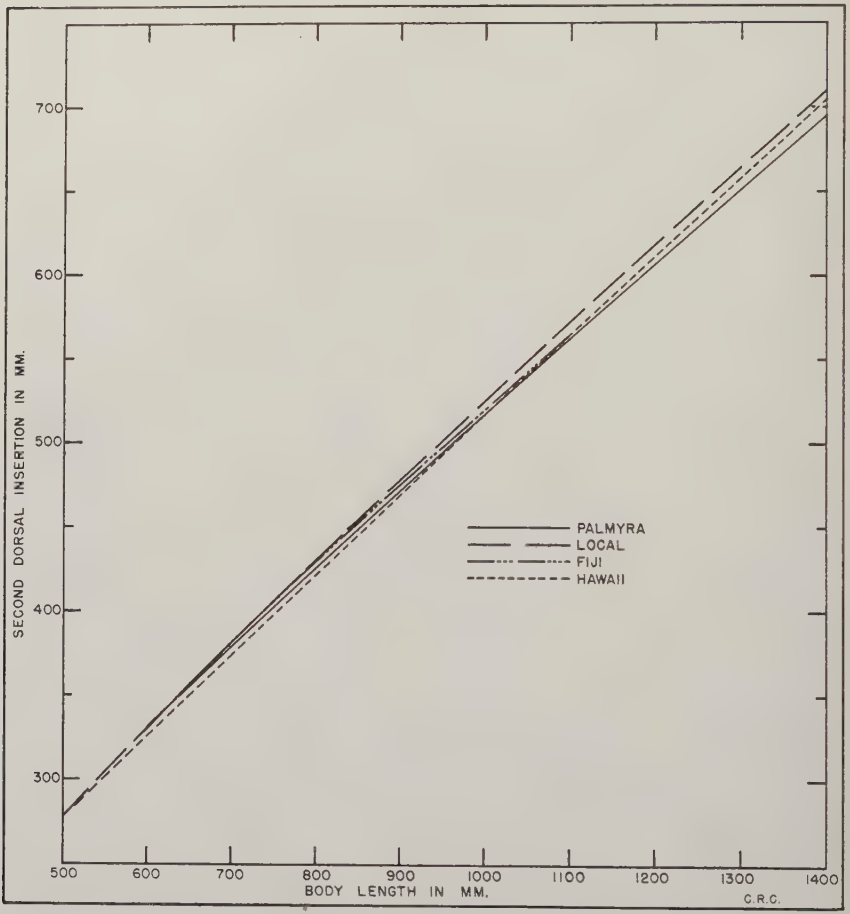

FIGURE 4. Comparison of the regression of second dorsal insertion on body length in the three central Pacific samples with the eastern Pacific population line

The Fijian sample is intermediate. The lower portion of this line is coincident with or extremely close to the eastern Pacific line, but from approximately 800 mm. body length the former diverges more and more, to approximate eventually the Hawaiian and Palmyra lines. In terms of mean square difference this divergence is several times greater than anticipated variation in local samples. To this extent the Fijian sample may also be considered distinct from the eastern Pacific stock.

ANAL INSERTION ON BODY LENGTH

Figure 5, illustrating this regression, is in general similar to the foregoing. The differences, however, are more pronounced. The Hawaiian

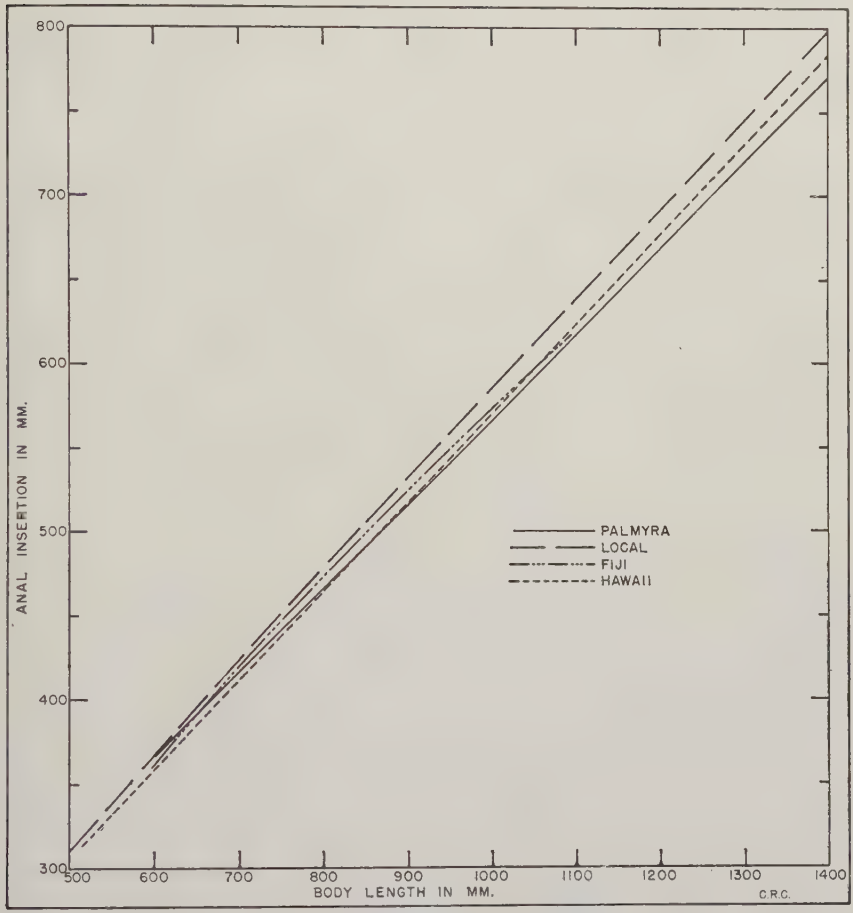

FIGURE 5. Comparison of the regression of anal insertion on body length in the three central Pacific samples with the eastern Pacific population line

and Palmyra samples, with mean square differences of 116 and 260 respectively, are clearly distinct from the eastern Pacific population. The Fijian sample is again intermediate in position. Over the lower portion of its range it lies closer to the eastern Pacific line than to the other central Pacific sample lines. As in the case of the second dorsal, it subsequently diverges from the local line to approximate at its upper extremity the Hawaiian and Palmyra samples. The mean square difference is excessively greater than any derived from a local sample, and on this basis the Fijian stock must be considered distinct from that of the eastern Pacific.

VENTRAL INSERTION ON BODY LENGTH

Figure 6, depicting this character, shows that the central Pacific samples are clearly distinct from the eastern Pacific stock. All central Pacific samples have a comparable slope and position, which differs appreciably from that of the eastern Pacific population. The mean square differences confirm the conclusion that in this character the central Pacific stock is clearly differentiated from that of the eastern Pacific.

DISCUSSION

In the five characters discussed all central Pacific samples diverge in every case from the eastern Pacific regression lines by amounts far in excess of anticipated variation of local samples. These numerical differences are reflected in the majority of the graphs. Visual inspection of the latter would alone suggest that the central Pacific stock differed in at least three characters. In general the slope of the central Pacific regression lines is less than that of the eastern Pacific lines. Excluding intersection at the lower size range, every central Pacific regression line falls below that of the eastern Pacific population line. In view of the fact that the foregoing observations are supported by extremely high F values resulting from application of analysis of variance, one must conclude that the central Pacific stock is distinct from that of the eastern Pacific.

COMPARISON WITH EARLIER RESULTS

It is of interest at this point to compare the above findings with those published in 1948. In that study the results showed that the Hawaiian fish differed significantly in three characters, the head length, anal and ventral insertions. In these three characters the Hawaiian specimens fell distinctly below the eastern Pacific population line. These results led to a tentative conclusion that the Hawaiian stock was different from that of the eastern Pacific, and hence to the assumption that if such were correct, then subsequent samples of Hawaiian yellowfin should differ from those of the eastern Pacific in like manner. In the original study, the head length, anal insertion and ventral insertion of the Hawaiian sample differed significantly from the corresponding eastern Pacific line, with the Hawaiian values falling distinctly below the latter. In the present study it is these three characters that differ most, and again the sample values fall appreciably below the local line. In the remaining two regressions, the first and second dorsal insertions, there were no significant differences in the earlier comparison, whereas in the present study the Hawaiian sample yields significant F values and large mean square differences. However, these values are not as great as in the remaining three regressions. In all cases the present Hawaiian regression lines fall below the eastern Pacific lines. A comparison of the two Hawaiian samples by means of analysis of variance indicates that no significant differences exist between the two samples in four of the five regressions tested. In one, the regression of ventral insertion upon body length, the resulting F value indicates a probability approximating the 1 percent level of significance. In Figure 6 the short regression line of the original Hawaiian sample is shown for comparison. It has been omitted in the remaining figures because the line of this sample approximates the others so closely as to preclude reproduction. In general, the

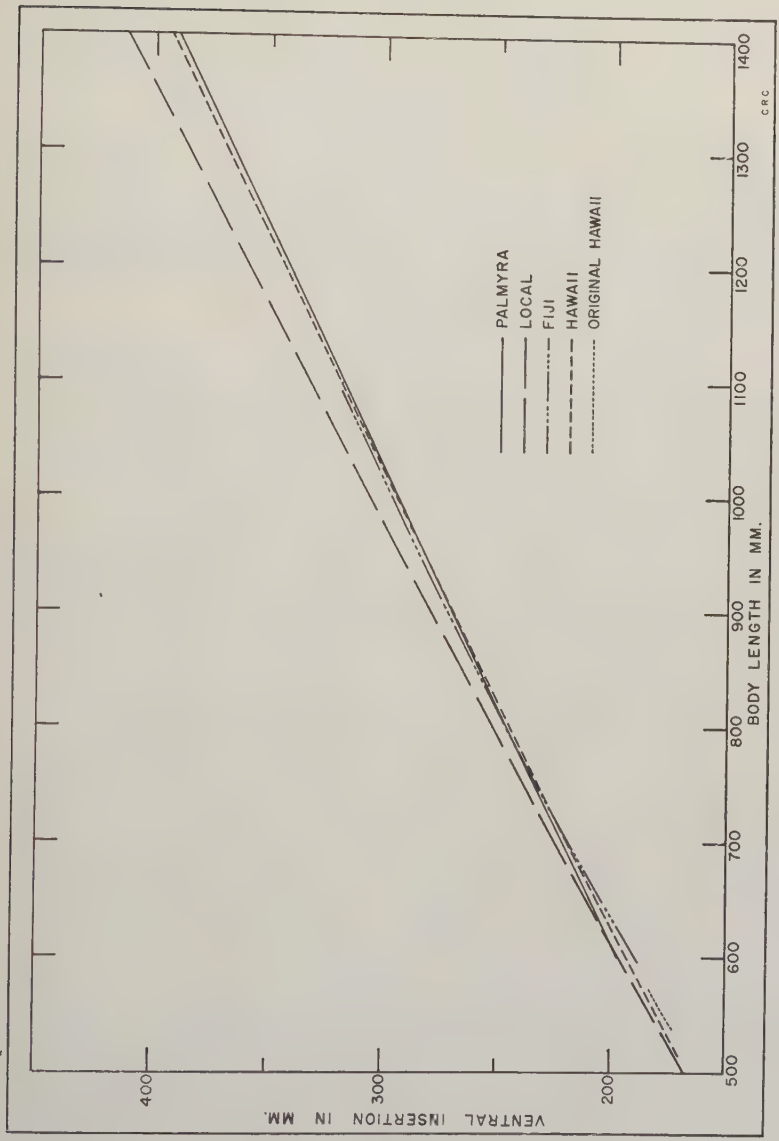

FIGURE 6. Comparison of the regression of ventral insertion on body length in the three central Pacific samples with the eastern Pacific population line

present data are in close agreement with the original findings, and support the preliminary conclusions. The probability of their correctness is therefore considerably augmented.

HOMOGENEITY OF THE CENTRAL PACIFIC STOCK

Though beyond the original intent of this investigation it is nonetheless interesting to investigate the homogeneity of the central Pacific stock of yellowfin tuna. For this purpose four samples are available, namely, the three discussed in this paper, and the original Hawaiian sample of 12 fish.

If these four samples are combined into a single, central Pacific sample, the homogeneity of this stock may be tested by means of analysis of variance, in which the sums of squares of the several samples, measured from the individual sample lines, are added together and compared (with the corresponding degrees of freedom) with the sums of squares measured from the combined sample line, thus:

Head Length on Body Length

Source of variation	*Sum of Squares*	*D. F.*	*Mean square*
Deviations from combined central Pacific line	4,162.1089	195	
Deviations from (4) individual sample lines	2,936.4299	186	15.7873
Difference between lines	1,225.6790	9	136.1866

$$F = \frac{136.1866}{15.7873} = 8.626 \qquad P = \text{less than } .001$$

A summary of such analyses is shown with the resulting probabilities in Table 6. In these comparisons no correction has been made for the effects of freezing. From this it appears that the central Pacific stock may not be considered statistically homogeneous.

TABLE 6

Summary of Results of a Test of Homogeneity, Using Analysis of Variance, of the Four Central Pacific Samples

Regression	D. F.	F Value	Probability
Head Length	9/186	8.63	Less than .001
1st Dorsal	9/186	6.60	Less than .001
2nd Dorsal	9/185	3.01	About .001
Anal	9/186	4.62	Less than .001
Ventral	9/185	1.96	About .05

A study of the graphs (Figures 2 to 6) will show that in one character, the ventral insertion, all the central Pacific samples are extremely similar. In the remaining four there is at some point in the range a considerable spread in position. Moreover, the differences are not consistent. In two regressions, the second dorsal and anal insertions, the Palmyra and Hawaiian samples are more akin, with the Fijian sample divergent; while in the remaining two, the head length and the first dorsal insertion, the Fijian and Hawaiian samples are more alike, with the Palmyra sample differing. In general, the Palmyra sample, by reason of a consistently lesser slope, appears to be the nonconforming one, suggesting a possible difference in origin or stock.

If one uses the regressions of the Hawaiian sample collected in 1948 as reference lines, and computes the differences between the divergence of the other central Pacific samples from these reference lines and from their own sample regression lines, the results are those shown in Table 7. In this, the original Hawaiian sample, the Palmyra and the Fijian sample have been adjusted for the effects of freezing.

TABLE 7

The Differences Between the Mean Squares Computed From the Sample Lines, and From the 1948 Hawaiian Line

Sample	Head length	First dorsal	Second dorsal	Anal	Ventral
Original Hawaiian	0.7342	8.7845	3.8639	10.1443	11.5125
Palmyra	18.5727	23.1484	7.7171	16.2261	2.3953
Fijian	2.1464	4.1861	10.1561	22.5980	4.6425

In a comparison of the Palmyra sample with the 1948 Hawaiian lines, the mean square differences are high in the case of head length, first dorsal insertion and anal insertion. In the case of the anal insertion the difference is only slightly in excess of observed variation within the eastern Pacific stock, whereas in the regression of head length and first dorsal the divergence is much greater than one would anticipate in a homogeneous stock. This suggests the need for further study, and indicates a probable difference between the Palmyra and Hawaiian stocks of yellowfin.

In the comparison of the Fijian with the Hawaiian stock, the mean square differences are relatively high in the case of the second dorsal and the anal insertion. In view of this one must conclude from the present data that there are indications of differences between the Fijian and Hawaiian stocks, but further studies based on larger samples of fresh material are needed to confirm this.

The two Hawaiian samples are very similar in head length and second dorsal insertion, and relatively so in the case of anal insertion. In the two remaining characters the differences are in excess of the maximum divergence recorded for the eastern Pacific stock. However, one important consideration must be kept in mind in evaluating all these comparisons. In measuring the divergence in samples from the eastern Pacific, this was done from relatively accurate parameters obtained by combining all (13) samples. The resulting regressions are therefore averages, and the divergence from these averages of any one sample would be less than the corresponding differences between extreme samples. The present comparisons of individual samples from the central Pacific, however, are between samples, and therefore greater resulting differences must be anticipated. Until such time as more reliable population parameters become available, the present results must be considered only indicative.

In general, this preliminary survey shows that the several central Pacific samples differ appreciably from one another in some regressions, leading to a suspicion that the stock may be composed of two or more distinct units. In particular, the consistently lesser slope of the Palmyra sample merits investigation.

SUMMARY AND CONCLUSIONS

This study was designed to test the preliminary conclusion that the stock of yellowfin tuna in the central Pacific differs from that of the eastern Pacific.

Three additional samples were obtained from the central Pacific, originating respectively in the Hawaiian, Palmyra and Fijian area.

Standard methods of analysis of variance are employed, and these are supplemented by an objective comparison of regression lines in terms of the mean square distance separating them.

The effects of freezing and cold storage of samples are investigated. The proportional change in measurements and the displacement of the resulting regression lines is small but consistent. Approximate corrections for this effect are developed.

Results of this study confirm the earlier findings and enhance considerably the probability that the central Pacific stock is distinct from and nonintermingling with that of the eastern Pacific.

A comparison of the four samples available from the central Pacific does not warrant positive conclusions. There are, however, indications that the stock within this large region may itself consist of separate discrete units. In particular, the Palmyra sample regression lines have a consistently lesser slope.

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APPENDICES

Appendix A: Tabulation of original measurements and derived values

Appendix B: Observations on the anatomy of the Fijian yellowfin

APPENDIX A

HAWAIIAN SAMPLE

"N. B. Scofield" catch plus market specimens

Body length	Head length	1st dorsal insertion	2d dorsal insertion	Anal insertion	Ventral insertion
		"N. B. Scofield" catch			
mm.	mm.	mm.	mm.	mm.	mm.
514	146	160	283	312	163
526	150	168	286	314	171
529	151	161	290	315	172
532	157	171	297	327	176
534	153	167	287	316	173
535	147	166	289	318	168
538	157	172	295	327	180
545	156	172	303	335	176
548	157	169	302	334	179
549	157	173	302	333	183
553	159	174	304	335	182
554	158	170	303	332	181
558	158	168	301	332	182
561	161	175	303	341	181
562	161	179	312	344	184
564	159	171	305	336	179
565	162	178	312	342	184
567	162	178	313	343	187
567	160	179	312	344	184
567	163	179	308	338	185
568	162	177	313	345	192
569	160	174	316	342	180
569	162	176	310	339	187
570	160	178	312	341	183
571	162	172	304	338	188
572	162	175	311	348	189
573	168	180	313	347	194
573	164	181	318	351	190
576	163	177	314	349	187
578	163	184	317	346	188
579	169	182	320	354	190
582	168	186	317	355	192
583	163	177	315	351	184
583	167	181	321	353	193
584	161	177	316	346	183
584	163	179	320	356	182
588	163	183	317	351	186
590	168	183	321	354	195
594	170	187	326	357	197
597	167	182	323	358	191
598	172	186	330	363	196
600	169	186	324	360	194
613	179	191	334	366	197
628	174	195	342	375	197
632	181	202	343	375	205
652	185	200	349	386	206
816	227	249	431	479	255
816	225	246	430	466	255
821	224	248	427	470	249
825	222	242	439	469	247
836	227	247	436	483	252
837	227	247	434	483	250
846	230	255	451	491	255
846	232	250	444	490	259
851	230	250	443	488	257

HAWAIIAN SAMPLE—Continued

Body length	Head length	1st dorsal insertion	2d dorsal insertion	Anal insertion	Ventral insertion
		Market specimens			
mm.	mm.	mm.	mm.	mm.	mm.
519	150	165	285	314	169
889	237	261	468	513	265
896	242	264	472	526	275
1,186	302	332	614	675	345
1,332	330	383	673	743	366
1,349	335	378	678	766	384
1,355	335	378	688	759	378
1,361	336	369	689	771	378
1,370	343	384	690	771	382
1,375	339	387	697	764	382
1,379	341	375	676	757	376
1,405	352	379	694	768	402
1,405	348	384	703	783	396
1,410	361	393	716	790	401
1,416	363	399	721	789	405
1,445	356	384	724	812	400
1,450	365	411	731	813	412
1,457	369	406	721	830	415
1,465	358	402	742	829	403
1,469	369	402	726	825	412
1,477	369	414	749	821	412
1,479	366	407	739	822	409
1,555	388	442	779	873	430
1,638	419	463	840	911	466
		Totals			
ΣY	17,596	19,377	34,503	38,168	19,878
No.	79	79	79	79	79
ΣX	65,850	65,850	65,850	65,850	65,850
ΣX^2	65,532,664	65,532,664	65,532,664	65,532,664	65,532,664
$\Sigma\frac{1}{X}$	.1105654308	.1105654308	.1105654308	.1105654308	.1105654308
$\Sigma\left(\frac{1}{X}\right)^2$	.0001717413321	.0001717413321	.0001717413321	.0001717413321	.0001717413321
$\Sigma\frac{1}{X}Y$	21.62566004	23.74758018	42.03403043	46.42339229	24.50829696
ΣXY	17,086,214	18,873,311	33,814,845	37,473,576	19,242,824
ΣY^2	4,470,350	5,450,727	17,472,291	21,451,350	5,675,070
a	65.843326	53.239415	55.65728626	32.73999612	63.11696195
b	.2107177273	.2449711919	.4674080979	.53534166	.2405700836
c	—13,398.26635	—8,685.05428	—6,084.6219	+2,978.2546	—8,590.20758
Mean square	14.5444	24.53655	30.08167	29.1489	21.7039

PALMYRA SAMPLE

Body length	Head length	1st dorsal insertion	2d dorsal insertion	Anal insertion	Ventral insertion
mm.	mm.	mm.	mm.	mm.	mm.
594	169	185	328	357	189
651	188	199	349	390	205
652	197	215	364	391	212
654	192	209	354	392	210
656	192	210	358	396	207
669	195	215	363	403	216
670	200	219	369	396	215
681	202	223	381	414	220
683	204	213	——	408	218
691	203	221	375	417	220
697	197	217	370	406	217
705	208	231	382	425	226
713	212	238	394	424	222
718	201	218	383	424	228
719	207	226	387	424	227
727	213	232	393	428	236
727	213	231	395	435	227
733	207	236	394	432	228
741	211	233	394	441	232
744	214	224	397	444	236
750	213	234	407	445	232
750	216	240	408	453	233
751	213	235	404	436	233
752	211	230	400	450	233
758	211	226	398	448	231
760	217	243	414	447	236
764	223	242	411	451	245
770	216	233	399	449	237
772	218	239	411	448	241
781	229	248	419	454	251
782	223	238	414	464	247
785	228	245	420	466	249
787	221	242	413	448	242
790	216	235	414	455	240
795	227	250	429	470	250
807	230	246	422	468	243
815	220	239	422	471	247
818	228	248	425	460	253
834	232	258	450	481	256
840	243	259	456	507	269
843	231	260	439	481	252
861	233	256	454	482	253
862	231	256	450	497	261
862	240	266	463	507	264
864	236	253	448	496	261
875	240	258	456	499	269
877	240	275	466	504	262
880	239	259	458	500	262
883	232	257	451	514	260
883	245	268	465	516	269
886	236	258	457	511	264
893	242	264	468	520	275
897	241	267	470	520	272
903	245	266	483	516	271
906	248	268	470	520	281
910	248	269	479	522	273
917	249	271	481	529	273
918	249	274	480	527	275
919	254	279	487	517	278
920	246	273	484	541	273
925	250	265	483	536	277
928	249	269	481	532	275
934	249	272	477	537	279
939	248	274	482	537	279
940	254	278	480	545	284
944	259	289	500	540	280

PALMYRA SAMPLE—Continued

Body length	Head length	1st dorsal insertion	2d dorsal insertion	Anal insertion	Ventral insertion
947	251	281	489	538	281
949	252	276	490	554	276
952	263	294	501	547	288
954	258	279	489	542	284
956	256	283	502	543	281
958	262	279	492	548	291
962	260	277	492	566	296
967	251	288	511	536	270
969	264	286	503	556	288
979	257	287	511	558	290
981	262	294	519	559	284
987	258	289	521	557	284
993	265	293	518	571	292
996	266	299	519	557	292
1,006	262	291	526	565	291
1,011	269	293	510	568	296
1,017	267	291	522	569	295
1,028	277	305	529	577	300
1,037	272	299	536	585	307
1,048	277	303	532	581	309
1,053	276	305	541	591	307
1,073	283	308	548	590	308
1,077	281	302	540	600	306
1,086	292	314	557	613	315
1,159	298	323	582	646	333
1,169	300	336	594	645	330
1,204	310	347	610	687	350
1,409	356	379	700	784	399

Totals

ΣY	22,439	24,570	42,562	47,197	24,724
No.	94	94	93	94	94
ΣX	81,782	81,782	81,099	81,782	81,782
ΣX^2	73,048,690	73,048,690	72,582,201	73,048,690	73,048,690
$\Sigma \frac{1}{X}$	.110865161	.110865161	.109401032	.110865161	.110865161
$\Sigma \left(\frac{1}{X}\right)^2$	.0001340887312	.0001340887312	.0001319450575	.0001340887312	.0001340887312
$\Sigma \frac{1}{X} Y$	25.94737061	28.40337482	48.97087666	54.42859321	28.56546307
ΣXY	19,922,256	21,818,368	37,964,472	42,018,676	21,969,215
ΣY^2	5,442,345	6,528,032	19,869,426	24,184,055	6,615,848
a	54.97026641	100.6969664	87.03146923	40.79405252	60.49083208
b	.2110036685	.2094130967	.4409346815	.5169120865	.2374542630
c	+139.74579	—18,235.99675	—11,803.25594	+9,816.02154	—3,442.22430
Mean square	16.72399	29.99339	36.08632	47.49337	20.40045

FIJIAN SAMPLE

Body length	Head length	1st dorsal insertion	2d dorsal insertion	Anal insertion	Ventral insertion
mm.	mm.	mm.	mm.	mm.	mm.
596	166	182	332	367	187
638	182	197	347	379	204
660	184	198	361	394	205
840	231	248	444	495	258
863	234	258	457	506	265
873	239	269	468	515	265
976	256	285	511	561	291
1,007	267	296	528	586	301
1,033	273	296	530	579	298
1,051	272	300	549	593	308
1,054	285	310	545	610	—
1,090	278	313	551	610	323
1,092	287	320	560	616	320
Totals					
ΣY	3,154	3,472	6,183	6,811	3,225
No.	13	13	13	13	12
ΣX	11,773	11,773	11,773	11,773	10,719
ΣX^2	11,040,153	11,040,153	11,040,153	11,040,153	9,929,237
$\Sigma\frac{1}{X}$	.01497421862	.01497421862	.01497421862	.01497421862	.01402545202
$\Sigma\left(\frac{1}{X}\right)^2$	.00001809845672	.0000180984567	.0000180984567	.0000180984567	.0000171982987
$\Sigma\frac{1}{X}Y$	3.501277482	3.848725638	6.860832368	7.556250445	3.629844204
ΣXY	2,944,541	3,245,299	5,774,894	6,362,147	2,973,839
ΣY^2	785,990	954,492	3,022,395	3,668,515	891,303
a	151.3411366	133.1939085	189.0146688	257.8553658	136.6157651
b	.1619329046	.2028449475	.3845022769	.3949112793	.2015653571
c	—48,074.0186	—43,248.6260	—53,487.6660	—79,497.3202	—40,994.63214
Mean square	12.4967	15.5646	17.4862	36.9349	8.1971

APPENDIX B

OBSERVATIONS ON THE ANATOMY OF THE FIJIAN YELLOWFIN

In July, 1950, one of the local canners received a small shipment of yellowfin tuna from the Fiji Islands. Initial observations suggested that these fish differed slightly in appearance from locally caught yellowfin tuna. The caudal region appeared more elongate and the height of the second dorsal and anal fins seemed greater in proportion to body length. As the measurements made upon fish of this shipment were intended for a population study of yellowfin tuna, we took the precaution of acquiring two specimens of this lot for a more detailed study in order to determine whether or not they were actually *Neothunnus macropterus*.

Complete dissections were made of these two specimens according to the procedure described by Godsil and Byers (1944), and in every respect the condition in these Fijian specimens agreed with that described for *N. macropteus*. Variations encountered in the several systems examined were all within the limits observed in the earlier material, and diagnostic characters in every case identified these specimens positively with this species.

Regarding the observed apparent differences, the measurements show that the caudal region was in fact slightly more elongate than in the eastern Pacific stock. Figures 2 to 6 show that, for the central Pacific fish in general, the head length is shorter and the insertion of all the fins is more anterior than in the eastern Pacific stock. This slight difference was accentuated in appearance by the fact that the Fijian fish were relatively thin.

The apparent greater height of the second dorsal and anal fins was not substantiated by the measurements. The latter were well within the range established for the eastern Pacific population. Any difference in modal height that might exist would at most be of a population rather than a specific nature.

The several measurements and meristic counts made upon these two specimens are appended for the record.

MEASUREMENTS AND COUNTS OBTAINED FROM TWO YELLOWFIN TUNA FROM THE FIJI ISLANDS

Measurements in millimeters

	Fish No. 1	Fish No. 2
External		
Body length	1,000	868
Head length	258	230
Insertion 1st dorsal	293	262
Insertion 2d dorsal	518	465
Insertion anal fin	564	512
Insertion ventrals	285	260
Greatest body depth	242	225
(Location of above)	VI-VII dorsal spine	VII dorsal spine
Greatest body width	180	167
(Location of above)	VIII dorsal spine	V dorsal spine
Dorsal-ventral distance	234	213
Dorsal-anal distance	361	327
Length of 1st dorsal base	236	213
Length of pectoral	292	251
(Posterior extension of pectoral)	---	4th dorsal ray
Spread of caudal	---	287
Height of 1st dorsal	---	95 (approx.)
Height of 2d dorsal	165	121 (frayed)
Height of anal	185	135
Length of 2d dorsal base	107*	93*
Length of anal base	88*	68
Diameter of iris	36.5	33
Maxillary length	102	91
Ventral fin insertion to vent	281	261
Internal		
Length of body cavity	338	314
Coecal mass	157	174
Liver, center lobe	45	22
Stomach	277	296
Intestine, anterior loop	141	150
posterior loop	279	256
Air bladder	181	133
Counts		
1st dorsal spines	XIII	XIII
2d dorsal rays	15*	15
Dorsal finlets	8	8
Anal rays	14*	14
Anal finlets	8	8
Gill rakers	11–20	---

* Including first finlet.

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* No. 1. Report on Fish Conditions. 1913; 48 pp., 3 figs.
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